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(54) Photoresist having increased sensitivity and use thereof

(57) The sensitivity of a photoresist to actinic light is improved by the addition of certain dyes. The photoresist includes a polymer matrix, a photosensitive acid generator and at least one compound selected from the group consisting of dyes containing at least one hetero-sulphur atom such as 2,2',1',5',2''-terthiophene and its derivatives; thianthrene and its derivatives, and 4,6-diphenylthieno(3,4-d)-1,3-dioxol-2-one-5,5-dioxide; phenylsulfone and its derivatives; and 4,5-diphenyl-1,3-dioxol-2-one; 3,4-bis(acetoxymethyl)furan; chelidonic acid and its derivatives; and 5,7,12,14-pentacenetetronone. Resist images on a substrate are formed from the compositions.

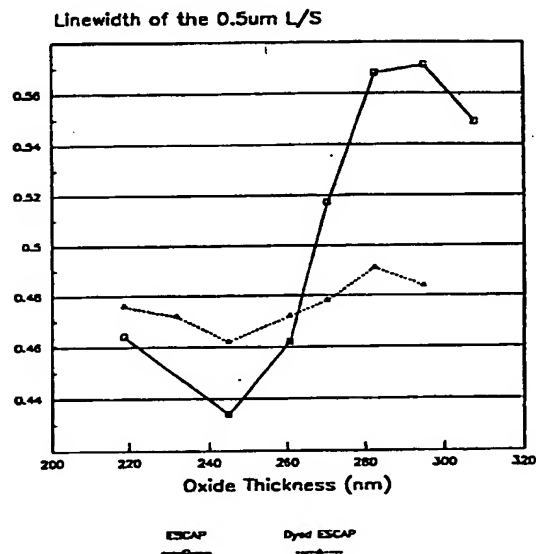


Figure 1. The ESCAP swing curve with and without dye.

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Description

Technical Field

The present invention is concerned with improving the sensitivity and lithographic properties of photoresists and particularly chemically amplified photoresists. The present invention is of particular importance in deep UV applications. The addition of certain dyes to photoresist composition containing a polymer matrix and photosensitive acid generator significantly increased its sensitivity and improved its lithographic properties including reducing the swing curve and permitting control of reflective notching.

Background of Invention

The design of chemically amplified resist systems based on acid-catalyzed chain reactions (e.g., polymerization, depolymerization, side chain cleavage, etc.) has been recognized as a viable route to high sensitivity resist systems in microlithography. Such systems are described in, e.g., Polymers In Electronics, Davidson T. Ed., ACS Symposium pages 11, H. Ito, C.G. Willson. These systems offer the high sensitivity attendant with chemical amplification but avoid the drawbacks of free radical based systems. Systems of this type are capable of high resolution, i.e., submicron in the case of semiconductor applications. Since they are oxygen insensitive, they can be applied in liquid form as thin films.

Photoresists which function via an acid-catalyzed deprotection mechanism utilize polymers which are positive acting. That is, the unexposed resist is insoluble in the developer, but is converted into a soluble material upon exposure. Chemically, this is accomplished by changing the side group chemistry through thermal cleavage, a reaction which is acid-catalyzed.

Compounds such as iodonium salts generate acid upon photo or thermally induced decomposition.

These materials, however, could stand further improvement with respect to sensitivity to the actinic light employed and especially when deep UV is employed. These materials also suffer from another problem commonly referred to as "swing curve." In particular, as the resist thickness varies, for instance, due to wafer topography, the linewidth changes. It could, therefore, be desirable to reduce the linewidth variation from the minimum to the maximum on the swing curve. Likewise, it would be desirable to better control the reflective notching that occurs in such systems.

Summary of Invention

The present invention significantly increases the sensitivity of the photoresist to the actinic light employed along with improving certain of its lithographic characteristics. The present invention greatly reduces linewidth variation from minimum to maximum on the swing curve and helps to control reflective notching.

In particular, the present invention is directed to a photoresist composition that exhibits increased sensitivity comprising a polymer matrix, photosensitive acid generator, and certain compounds. The compounds include dyes having at least one heterosulfur atom such as 2,2',5',2"-terthiophene, and its derivatives, thianthrene and its derivatives, 4,6-diphenylthieno(3,4-d)-1,3-dioxol-2-one-5,5-dioxide; polythiophenes; 1,2-benzodiphenylene sulfide; tetraphenylthiophene and its derivatives; 4(2-thienyl) butyric acid and its derivatives; 3(2-thienyl) acrylic acid and derivatives; DL-thioctic acid and its derivatives; 3-thiophene malonic acid and its derivatives; 2-thiophene glyoxylic acid and its derivatives; and thenoyltrifluoroacetone. Other suitable compounds are phenylsulfone and its derivatives; 4,5-diphenyl-1,3-dioxol-2-one; 3,4-bis(acetoxymethyl)furan; chelidonic acid and its derivatives; and 5,7,12,14-pentacenetetrone.

The present invention is also concerned with the use of the above compositions to produce a resist image on a substrate. The method comprises coating the substrate with the above disclosed photoresist composition then imagewise expose the photoresist to actinic light, and then develop the photoresist to produce the desired resist image.

Summary of Drawing

Figure 1 is a graph illustrating the swing curve for a composition of the present invention and that for a composition outside the scope of the present invention.

Figure 2 is a graph illustrating the exposure latitude for a composition of the present invention and that for a composition outside the scope of the invention.

Figure 3 is a graph illustrating the increase in absorption achievable by the present invention.

Best and Various Modes For Carrying Out Invention

The present invention is concerned with a positive photosensitive resist composition that comprises a film forming reactive polymer containing groups which react upon acid catalysis; and an initiator which generates acid upon exposure to the actinic light, thereby producing acid catalysis of the film forming reactive polymer.

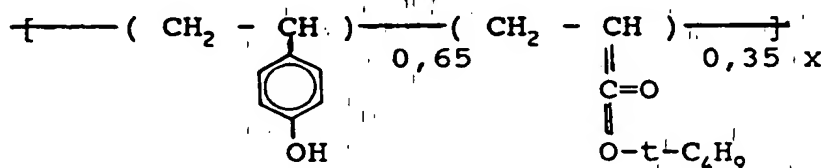
The preferred polymers of the present invention are vinylic polymers containing recurrent pendant groups that undergo efficient acidolysis to produce products that are very different in polarity (solubility) than their precursors. The invention, however, is not limited to polymers obtained by vinylic addition polymerization. Other polymerizations such as condensation, polyaddition, and addition condensation can be employed to synthesize polymers useful in the present invention.

The preferred acid labile pendant groups are tertbutyl esters of carboxylic acids and tertbutyl carbonates of phenols but, it is understood that a wide range of acid labile groups are operative in the invention. These include trityl, benzyl, benzyldryl modifications as well as others well known in the art.

The most preferred polymers employed contain phenolic hydroxy groups such as hydroxystyrene groups or novolak resins. These materials include copolymers thereof and include copolymers of hydroxystyrene and methacrylates and/or acrylates such as t-butyl methacrylate; poly(hydroxystyrene), poly(hydroxystyrene-co-t-butylloxycarbonyloxystyrene), poly(hydroxystyrene-co-hydroxymethylstyrene), poly(hydroxystyrene-co-acetoxymethylstyrene) alkyl substituted polyvinyl phenols and novolak resins such as cresol novolak, ethylphenol novolaks and xlenol novolaks.

Other suitable polymers are poly(p-tert-butoxycarbonyloxy- α -methylstyrene), poly(p-tert-butoxycarbonyloxystyrene), poly(tert-butyl p-vinylbenzoate), poly(tert-butyl p-isopropenylphenyloxyacetate), and poly(tert-butyl methacrylate).

The preferred polymer being represented by the following formula:



I

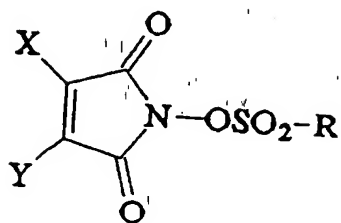
The compositions of the present invention also contain a photoinitiator and especially cationic initiators. In the event a positive working photoresist composition is desired, the photoinitiator employed is one which will generate a Bronsted acid upon exposure to actinic light. Examples of such photoinitiators are well-known and include onium salts and especially Group VIA and Group VIIA salts such as the pyrylium, selenonium, sulfonium, and iodonium salts. Various suitable photoinitiators are discussed in U. S. Patents 4,161,478; 4,442,197; 4,139,655; 4,400,541; 4,197,174; 4,173,476; and 4,299,938; and European patent application 44/0094914 and 84/0126712, disclosures of which are incorporated herein by reference.

Also see Watt, et al., "A Novel Photoinitiator of Cationic Polymerization: Preparation and Characterization of Bis[4-(diphenylsulfonio)phenyl]-sulfide-Bis-Hexafluorophosphate", Journal of Polymer Science: Polymer Chemistry Edition, Vol. 22, p. 1789, (1980) John Wiley & Sons, Inc.

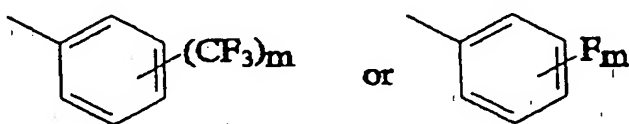
Additional discussions concerning sulfonium and iodonium salts can be found, for instance, in Crivello, et al., "Complex Triarylsulfonium Salt Photoinitiators. II. The Preparation of Several New Complex Triarylsulfonium Salts and the Influence of Their Structure in Photoinitiated Cationic Polymerization", Journal of Polymer Science: Polymer Chemistry Edition, Vol. 18, pp. 2697-2714 (1980) John Wiley & Sons, Inc.; Pappas, et al., "Photoinitiation of Cationic Polymerization. III. Photosensitization of Diphenyliodonium and Triphenylsulfonium Salts," Journal of Polymer Science: Polymer Chemistry Edition, Vol. 22, pp. 77-84, (1984) John Wiley & Sons, Inc.; Crivello, et al., "Photoinitiated Cationic Polymerization With Triarylsulfonium Salts," Journal of Polymer Science: Polymer Chemistry Edition, Vol. 17, pp. 977-999, (1979) John Wiley & Sons, Inc.; Crivello, et al., "Complex Triarylsulfonium Salt Photoinitiators. I. The Identification, Characterization, and Syntheses of a New Class of Triarylsulfonium Salt Photoinitiators," Journal of Polymer Science: Polymer Chemistry Edition, Vol. 18, pp. 2677-2695, (1980), John Wiley & Sons, Inc.; and Crivello, "Cationic Polymerization - Iodonium and Sulfonium Salt Photoinitiators," Advances In Polymer Science, Series #62, pp. 1-48 (1984), Springer-Verlag.

Typical of the onium salts are diaryliodonium and triarylsulfonium salts. These photoacids may include diphenyliodonium hexafluoroarsenate, di(t-butylphenyl)iodonium hexafluoroarsenate, diphenyliodonium hexafluoroantimonate, di(t-butylphenyl)iodonium hexafluoroantimonate, diphenyliodonium triflate, di(t-butylphenyl)iodonium triflate, triphenylsulfonium hexafluoroantimonate, triphenylsulfonium hexafluoroarsenate, tri(t-butylphenyl)sulfonium hexafluoroarsenate, triphenylsulfonium hexafluorophosphate, tri(t-butylphenyl)sulfonium hexafluorophosphate, triphenylsulfonium triflate and tri(t-butylphenyl)sulfonium triflate.

Among the non-metallic sulfonic acid precursors which generate strong acids upon exposure to radiation are N-sulfonyloximides of the form

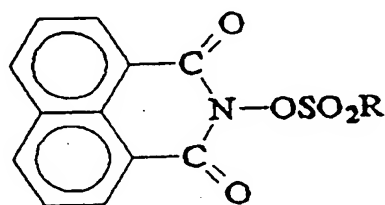


where R is selected from the group consisting of $-\text{CF}_3$, $-\text{CF}_2\text{CF}_3$, $-\text{CF}_2\text{CF}_2\text{H}$, $-(\text{CF}_2)_n-$ Z where n = 1 to 4, where Z is H, alkyl, aryl,



where m=1 to 5, where X and Y either (1) form a cyclic or polycyclic ring which may contain one or more hetero atoms, (2) form a fused aromatic ring, (3) may be independently H, alkyl or aryl, (4) may be attached to another sulfonyloxyimide-containing residue, or (5) may be attached to a polymeric chain or backbone.

The preferred initiator being represented by the following formula:



II

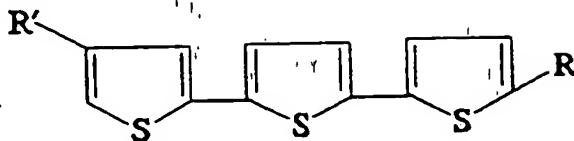
wherein R = $\text{C}_{10}\text{H}_{21}$.

The photoacid generator or initiator is generally present in the range from about 0.5 to 10% by weight, based on the weight of the polymer solids in the photoresist composition.

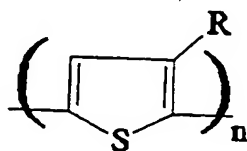
The compounds required according to the present invention must be capable of significantly increasing the absorption of the composition at 248 nm as compared to the composition without such compound; must not poison the composition and must be capable of withstanding the processing conditions including thermal treatments up to about 160°C. The following materials have been found pursuant to this invention to satisfy all of these requirements:

1. Dyes having heterosulfur group such as

a) 2,2',5',2"-Terthiophene and its derivatives:

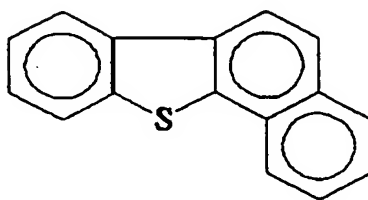


b) Polythiophenes

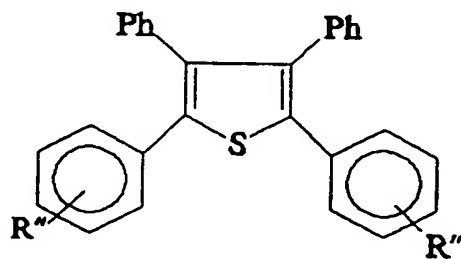


wherein $n = 10-100$

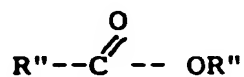
c) 1,2-benzodiphenylene sulfide



d) Tetraphenylthiophene and its derivatives



wherein R' is

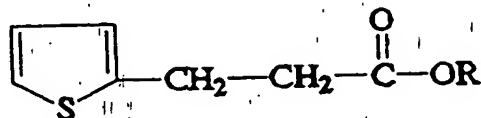


or alkyl having 1-12 carbon atoms and R'' is H or alkyl having 1-12 carbon atoms

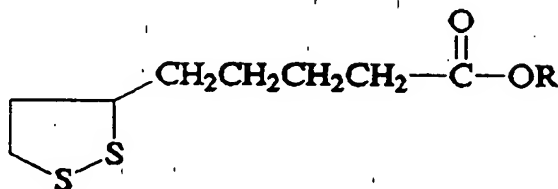
e) 4(2-thienyl)butyric acid and derivatives



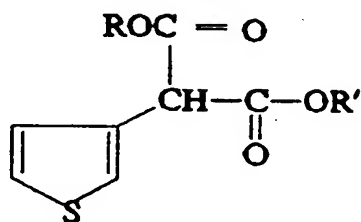
f) 3(2-thienyl)acrylic acid and derivatives



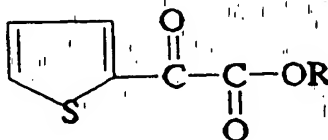
g) DL-thioctic acid and derivatives



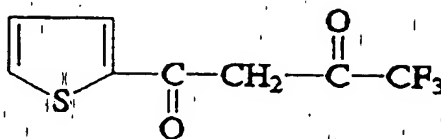
h) 3-thiophene malonic acid and derivatives



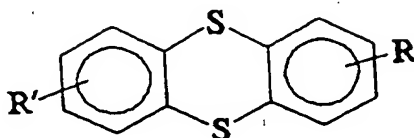
i) 2-thiopheneglyoxylic acid and derivatives



j) Thenoyltrifluoroacetone

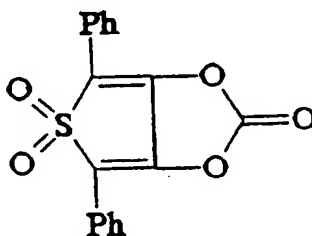


k) Thianthrene and its derivatives;

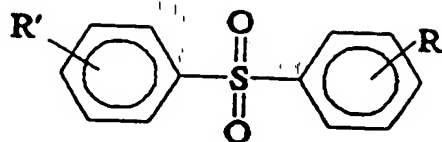


and;

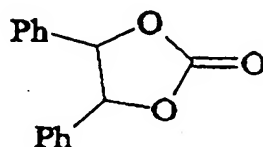
l) 4,6-Diphenylthieno(3,4-d-1,3-dioxol-2-one-5,5-dioxide;



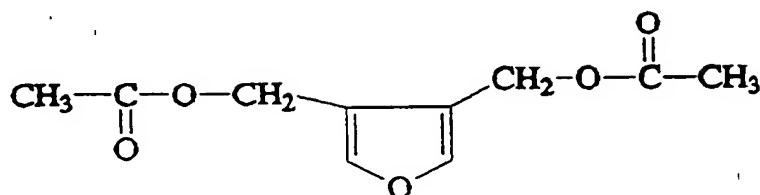
2) Phenylsulfone and its derivatives;



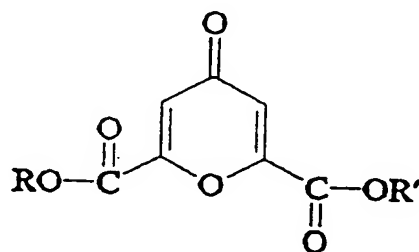
3) 4,5-Diphenyl-1,3-dioxol-2-one



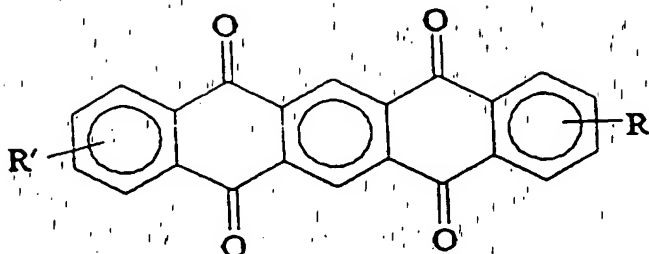
4) 3,4-bis(acetoxymethyl)furan



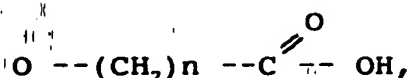
5) Chelidonic acid and its derivatives



6) 5,7,12,14 - Pentacenetrone



R and R" in the above formulae are individually selected from the group of H, alkyl having 1 to 12 carbon atoms, aryl having 6 to 18 carbon atoms,



--NO₂, --OR^{IV}, --OCH₂CH₂OR^{IV} wherein R^{IV} is H or alkyl having 1 to 12 carbon atoms.

The compound is typically employed in amounts of about 1 to about 20% atomic, and preferably about 5 to about 10% atomic based upon the polymer solids in the composition.

In addition, the compositions, when desired, can include an organic non-reactive diluent to facilitate the coating operation. Examples of suitable solvents include ketones such as methyl ethyl ketone, methyl isobutyl ketone and methyl amyl ketone, and methylene chloride, 1-methoxy-2-propyl acetate (A2 1500 thinner), (±)-1-methoxy-2-propanol, ethyl-3-ethoxypropionate, ethyl(S)-(-)-lactate, ethoxyethanol, diglyme(2-methoxyethylether). When employed, the diluent is present in the amount sufficient to provide compositions for coating application.

The compositions can be coated onto substrates such as semiconductor substrates, such as silicon, gallium arsenide and germanium silicide, metal, composites such as epoxy, cyanate ester, and polyimide based laminates, ceramics, and glass or other materials onto which photoprocessable coatings are normally employed. The compositions can be applied by various known coating techniques such as spinning, spraying, dipping, film laminating or passing the substrate through a bath of the composition.

The compositions after coating onto a substrate and removal of volatile solvents, if present, the coating is image-wise exposed to actinic light and preferably to deep UV light radiation in a predetermined pattern with energy ranging from 0 to about 100 MJ/cm². The exposure being through an image bearing transparency of the desired pattern.

The composition is then subjected to elevated temperatures of about 100°C to about 160°C and preferably about 130°C to about 160°C. This heating is usually carried out for about 1 to about 20 minutes and preferably about 1 to about 5 minutes.

After exposure to actinic light and subsequent heating, the coating is developed by removing areas struck by actinic light in the case of positive resist. This can be accomplished by immersing or spraying the film with a suitable developer. Some suitable developers include Shipley MF321 (tetramethyl ammonium hydroxide in water) or microposit 2401 (potassium hydroxide in water). The developer selected is one which will dissolve the exposed portions of the composition without attacking, to any undesired extent, the unexposed portions of the composition. Suitable developers can be readily determined by persons skilled in the art once they are aware of the present disclosure without undue experimentation.

Moreover, when desired, the film can be post-cured by subjecting the films to elevated temperatures such as about 100°C to about 160°C and preferably about 120°C to about 160°C for about 1 to about 10 minutes.

Typical film thickness of the composition are about 0.5 to about 10 microns and more typically about 1 to about 3 microns (dry).

The following non-limiting examples are presented to further illustrate the present invention:

Example 1

A deep UV formulation was prepared in PMA solution (about 17% solids), consisting of 2 g of the polymer matrix of formula I above, about 0.08 g of initiator compound of formula II above, about 0.17 g of thianthrene. The composition was coated on a silicon wafer, post-apply baked (PAB) at about 160°C for 2 min and then exposed on ULTRATECH

stepper (model X-248) or on GCA-248 Excimer laser stepper. The resist was then post-exposure baked (PEB) at about 150°C for about 2 min and developed in AZ 321 developer (tetromethyl ammonium hydroxide in water).

The effectiveness of the use of the dye in the composition was examined by measuring swing curves with and without the dye. The results are shown in Figure 1.

It was found that the variation in linewidth from minimum to maximum without the dye was 0.148 μ m. The addition of thianthrene (8.5% wt.) reduced the linewidth variation from minimum to maximum to 0.038 μ m.

In this example the sensitivity was enhanced by 48%. Measurements on ULTRATECH stepper showed sensitivity of 16 mJ/cm² for the dyed formulation compared to 29 mJ/cm² for the undyed version.

Both exposure and focus latitude were examined to see if the dye had an effect on the process window. The exposure latitude increased from 16% to 20% for the dyed resist at the same 0.35 μ m dimensions (see Figure 2).

The focus latitude decreased slightly from 1.2 U for undyed resist to 1.1 μ m for dyed resist for 0.35 U lines and spaces. UV spectra of dyed and undyed formulations are shown in Figure 3.

It can be seen that the absorption at 248 nm is about 6 times higher for the formulation with the dye compared to the undyed resist.

Example 2

A deep UV formulation was prepared according to Example 1 except that 1-thianthrene carboxylic acid was used. Sensitivities were measured by exposure on ULTRATECH stepper at 248 nm. For the dyed formulation it was 9 mJ/cm² compared to 40 mJ/cm² for the undyed version. UV measurements of 248 nm absorption for both dyed and undyed formulations before and after 160°C/2 min. showed the loss of the dye about 3.8% during PAB thermal treatment.

An increase of 248 nm absorption due to the addition of the dye was equal to 4.

Example 3

A deep UV formulation was prepared according to Example 1 except that instead of thianthrene, 2,2',5',2"-terthiophene was used. An increase in the sensitivity for the dyed formulation was about 45%.

Example 4

A deep UV formulation was prepared according to Example 1 except that instead of thianthrene, phenylsulfone was used. An increase in the sensitivity was 100%.

Example 5

A deep UV formulation was prepared according to Example 1 except that instead of thianthrene 4,6-diphenylthieno(3,4-d)-1,3-dioxol-2-one-5,5-dioxide was used. An increase in the sensitivity for the dyed formulation was 80%.

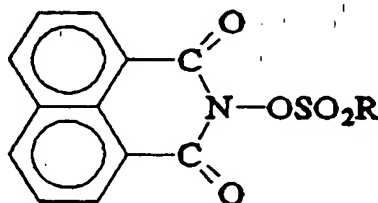
Example 6

A deep UV formulation was prepared according to Example 1 except that instead of Thianthrene, 4,5-diphenyl-1,3-dioxol-2-one was used. An increase in the sensitivity for the dyed formulation was 38%.

Claims

1. A photoresist having increased sensitivity comprising:
a polymer matrix,
a photosensitive acid generator, and
at least one compound selected from the group consisting of dye having at least one heterosulfur group; phenylsulfone, and derivatives thereof; and 4,5-diphenyl-1,3-dioxol-2-one; 3,4-bis(acetoxymethyl)furan; chelidonic acid and its derivatives; and 5,7,12,14-pentacenetetrone; and mixtures thereof.
2. The photoresist of claim 1 wherein said dye is selected from the group consisting of 2,2',5',2"-terthiophene and its derivatives; thianthrene and its derivatives; and 4,6-diphenylthieno(3,4-d)-1,3-dioxol-2-one-5,5-dioxide; polythiophenes; 1,2-benzodiphenylene sulfide; tetraphenylthiophene and its derivatives; 4(2-thienyl) butyric acid and its derivatives; 3(2-thienyl) acrylic acid and its derivatives; DL thioctic acid and its derivatives; 3-thiophene malonic acid and its derivatives; 2-thiopheneglyoxylic acid and its derivatives; and thenoyltrifluoroacetone.

3. The photoresist of claim 1 wherein said polymer matrix is selected from the group consisting of polymers of hydroxystyrene and acrylate or methacrylate or a mixture of acrylate and methacrylate.
4. The photoresist of claim 1 wherein said compound is selected from the group consisting of 2,2',5',1"-terthiophene or derivative thereof, thianthrene or derivative thereof, 4,6-diphenylthieno(3,4-d)-1,3-dioxol-2-one-5,5-dioxide, phenylsulfone or derivative thereof, or 4,5-diphenyl-1,3-dioxol-2-one.
5. The photoresist of claim 1 wherein said acid generator is a sulfonium or iodonium salt.
6. The photoresist of claim 1 wherein said acid gene



wherein R = C₁₀H₂₁.

7. A method for producing a resist image on a substrate comprising
 - a) coating the substrate with a photoresist having increased sensitivity comprising: a polymer matrix, a photosensitive acid generator, and a compound selected from the group consisting of dyes having at least one heterosulfur group; phenylsulfone and derivatives thereof; and 4,5-diphenyl-1,3-dioxol-2-one,
 - b) imagewise exposing the photoresist to actinic light, and
 - c) then developing the photoresist to produce the resist image.

Linewidth of the 0.5um L/S

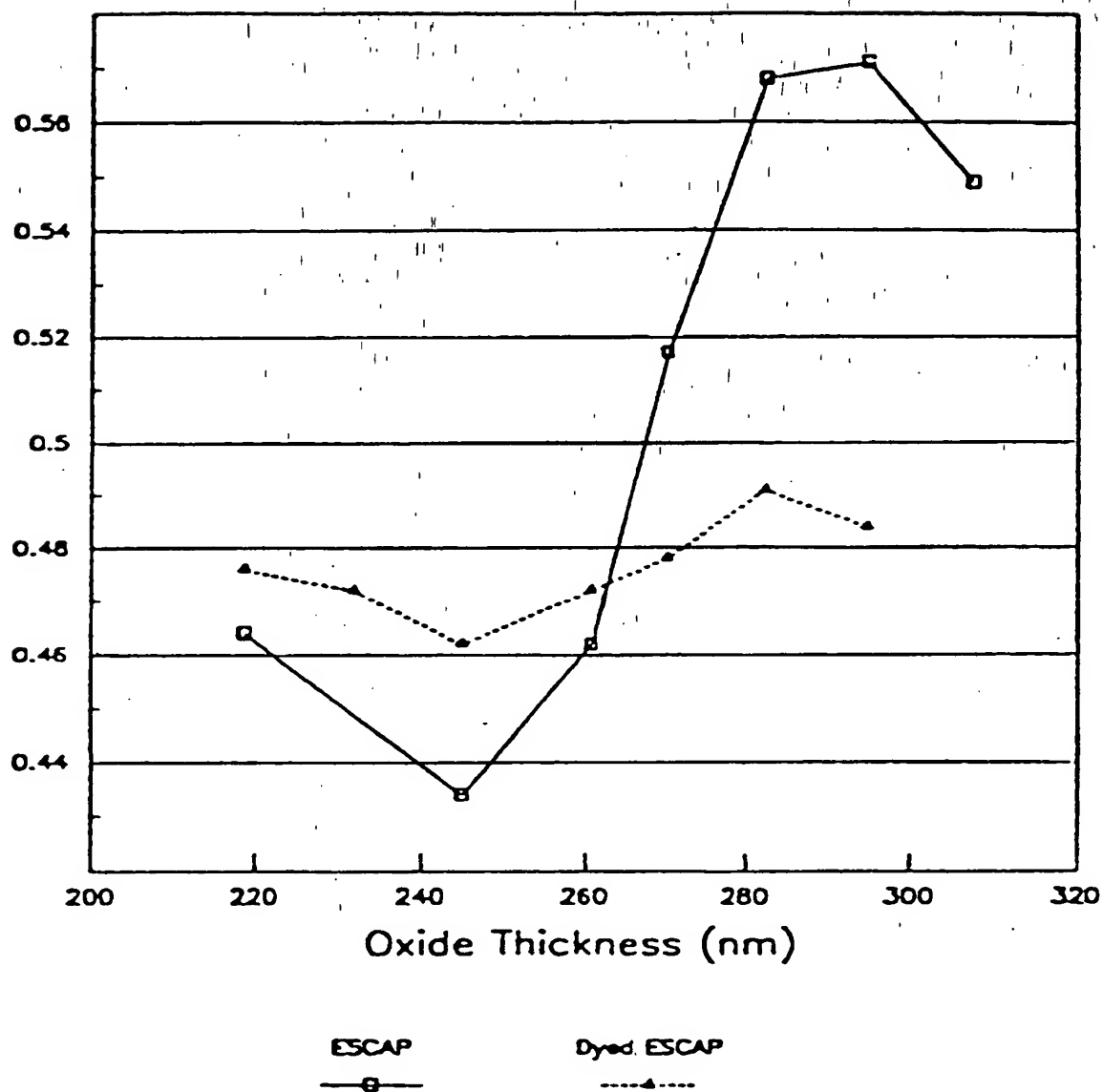


Figure 1. The ESCAP swing curve with and without dye.

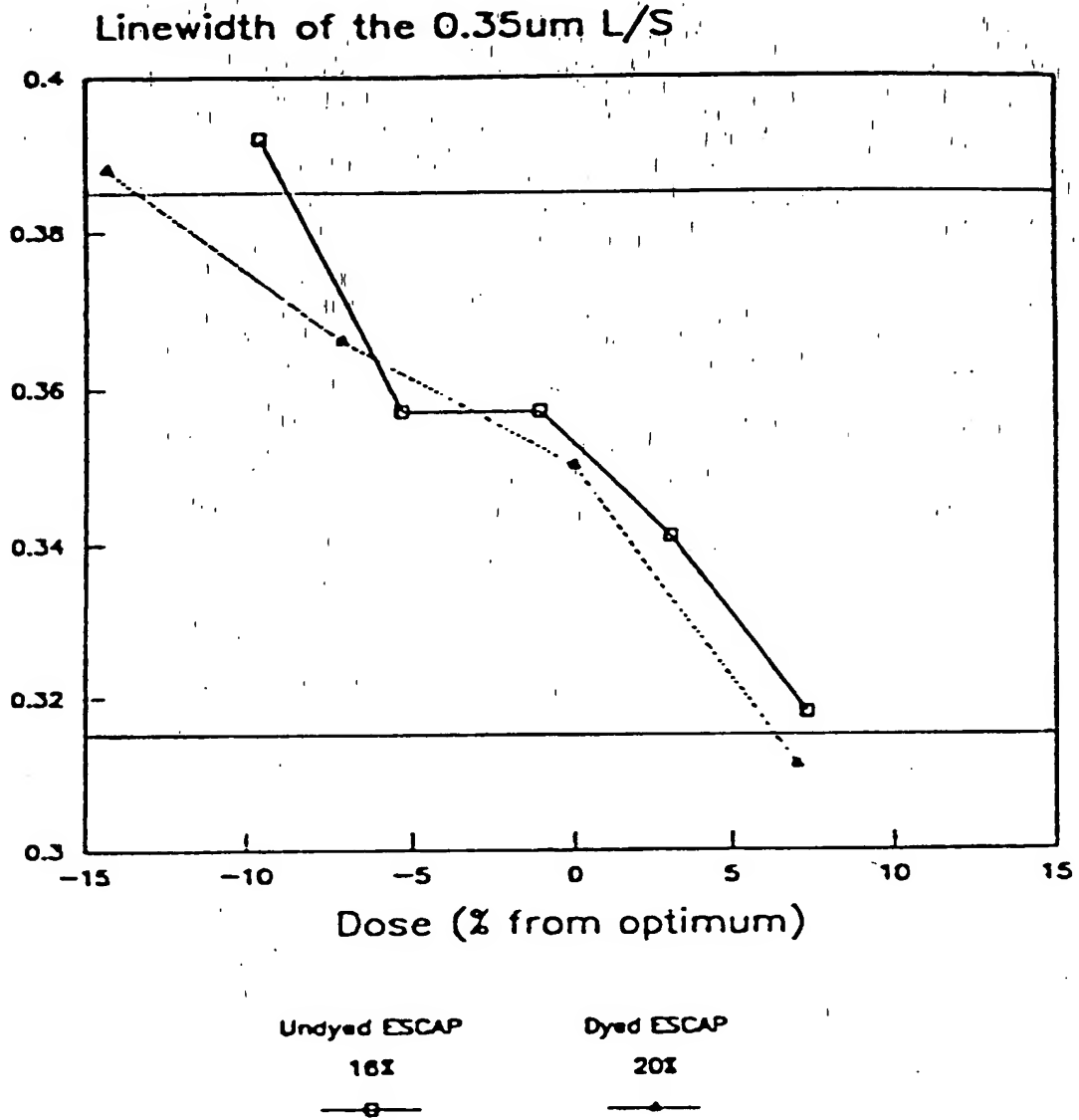


Figure 2. Exposure latitude at 0.35 μ m dimensions for dyed and undyed ESCAP.

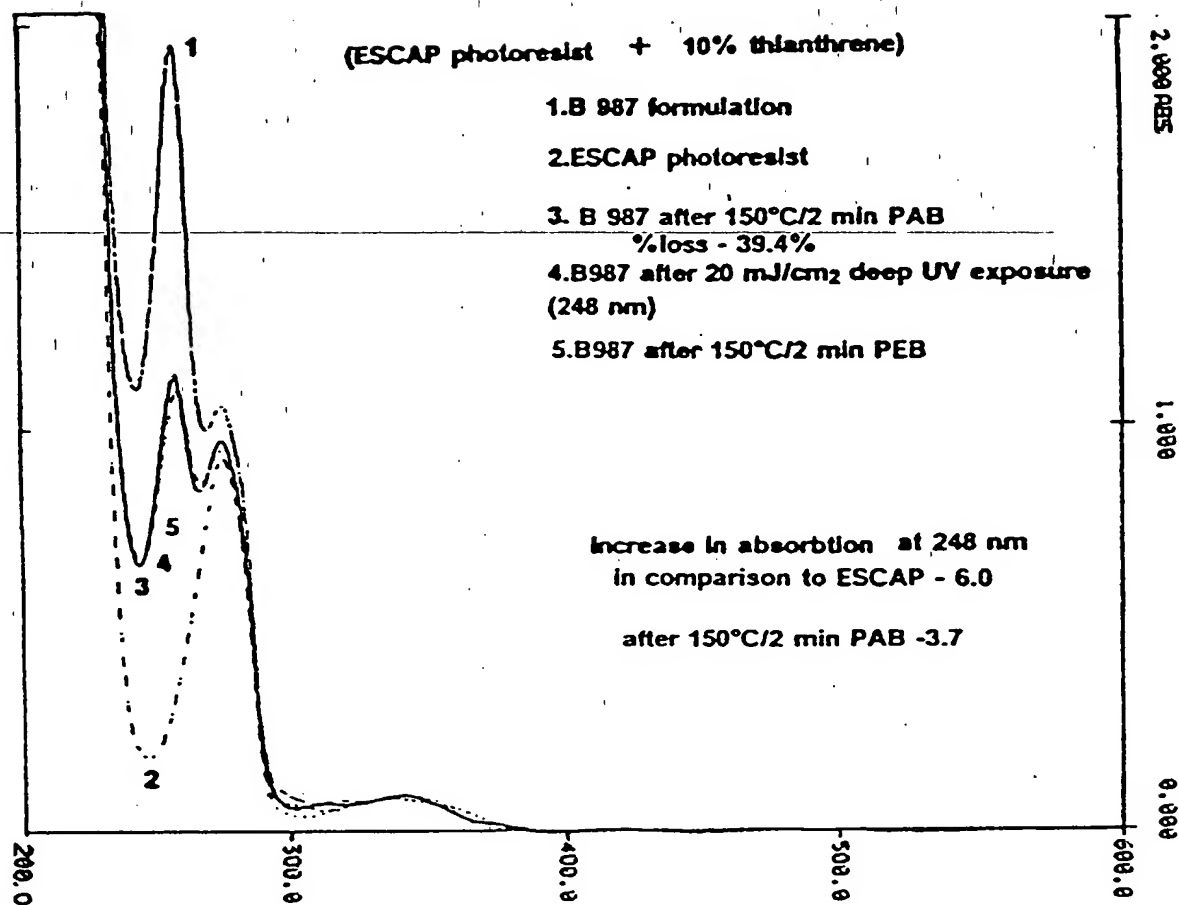


Figure 3



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 96 10 0483

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	EP-A-0 423 446 (SHIPLEY COMPANY INC.) 24 April 1991 * page 10; example 2 * * page 11, line 1 - line 8 * ---	1,7	G03F7/09
X	EP-A-0 455 223 (SUMITOMO CHEMICAL COMPANY, LIMITED) 6 November 1991 * page 17; examples 3-5 * * page 15, line 54 - line 58 * ---	1,7	
X	EP-A-0 523 715 (CANON KABUSHIKI KAISHA) 20 January 1993 * page 25 - page 25; examples 31,32,34,35 * ---	1,7	
X	EP-A-0 424 124 (MINNESOTA MINING AND MANUFACTURING COMPANY) 24 April 1991 * page 8, line 26 - line 30 * * page 12; example 5 * -----	1,7	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			G03F
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 5 June 1996	Examiner J.-M. DUPART
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